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The Metallurgist.

Supplement to The Engineer, *August, 1937.*

Physics and Metallurgy.

THE problems of metallurgy have opened up a new field for the specialist in physics and there is evidence that the theoretical physicists are turning active attention to the theory of the metallic state in the publication of many papers and several new books on the subject, such as "Properties of Metals and Alloys," by Mott and Jones; "Elektronentheorie der Metalle," by H. Fröhlich; and "The Theory of Metals," by A. H. Wilson.

It is satisfactory to note that there is also widespread interest among metallurgists in the fundamental developments of physics. That this is not only of recent growth is shown by the long list of May lectures of the Institute of Metals, many of which have been given by distinguished physicists on various aspects of the application of physics to metallurgy. The latest of these lectures, that by Professor Andrade on "The Flow of Metals," provides, among other matters, an example of quantitative prediction of the viscosity of liquid metals which may be applied with confidence to instances in which experimental determination offers very great difficulty.

The same interest is also indicated by the numerous conferences attended jointly by physicists and metallurgists in this country and elsewhere; such, for example, as the Royal Society discussion on "Fractures in Metals and Brittle Materials," last December; and the Birmingham Conference on Industrial Physics organised by the Institute of Physics in March of this year. At a symposium on "Metals" arranged by the American Institute of Physics last January the papers ranged from the fundamental theory of solids as derived from modern knowledge of the atom to specific practical problems which the steel industry is now studying, *e.g.*, minute non-metallic particles in steel, the transformation of austenite, corrosion, creep, rolling, &c. Many of the papers have since appeared in the recently reconstituted American *Journal of Applied Physics*, which, judging by the contents of the first few numbers, should prove to be a valuable source of information for the scientific metallurgist.

The physical theories of metals have in the past been very largely concerned with magnetic, electrical, and thermal properties; first of all in elucidation of the features common to all metals, later in explanation of the differences between individual metals and alloys in terms of the properties of their constituent atoms, and finally in quantitative prediction of properties. On the other hand, calculations based on quantum mechanics are only just beginning to be applied to the elastic constants of such metals as copper, and the mathematical physicists have hardly touched such practical problems as the theory of age-hardening or of other forms of hardening. It may therefore be a long time before they are in a position to predict, on purely theoretical grounds, the directions in which practical advances in the strength of materials are to be sought. In any event, these are matters which have been studied, and must continue to be studied, in an atmosphere remote from that of the industrial investigator.

Up to the present the actual practical application of the results of physical research to metallurgical investigation has been in providing the metallurgist with more firmly established and comprehensive generalisations to govern the direction of his work, in furnishing him with a greater insight into the structure of the materials with which he deals and into the mechanism of their failure under stress, and in supplying more accurate and speedier methods of approach to the solution of his problems.

These aids have been of incalculable service, but they are still mainly available in the research laboratories of universities and of large institutions, though they will undoubtedly extend to industrial research generally in course of time. They can only be applied in industry by the employment of physicists. There is a considerable danger that the academic physicist may find it difficult to adjust himself readily to industrial conditions, not because of any lack of adaptability on his part, but by reason of an insufficient realisation of the extraordinary progress that the metallurgist has made in evolving generalisations governing the constitution, treatment, and properties of metallurgical products. This can best be remedied by ensuring that physicists who intend to take up work in metallurgical industry receive systematic instruction in practical and theoretical metallography, either as a post-graduate course in a university or during a probationary period in the organisation to which they are attached. In other words, the physicist must have training, not only in his own subject, but in the application of his scientific knowledge. The advances which it is hoped that the work of the physicist will make possible are likely to be achieved with minimum delay if his work is carried out in an enlightened spirit of co-operation and fits well into the existing structure of metallurgical knowledge and practice.

The Use of Polarised Light in the Microscopical Examination of Iron and Steel.

By J. H. G. MONYPENNY, F. Inst. P.

No. II (*continued from June issue*).

NON-CUBIC STRUCTURAL CONSTITUENTS OF METALS.

Graphite lamellæ in cast iron were strongly double refracting and exhibited considerable variations in brightness when the sample was rotated between crossed nicols. Temper carbon is also double refracting.

Cementite, Fe_3C, is strongly double refracting and its presence could be clearly shown in unetched samples of hyper-eutectic cast iron by examination in polarised light. The carbide found in the cemented zone of a steel containing 2·5 per cent. chromium, 3·5 per cent. nickel, and 0·5 per cent. molybdenum was also strongly double refracting; as this carbide was shown by analysis to contain chromium, manganese, and molybdenum, in addition to iron, it may be assumed that the presence of these metals has not altered the non-cubic character of cementite.

When examining eutectoid steel having a coarsely lamellar structure, the authors found that all the lamellæ of carbide in any one grain lit up at the same time on rotation and all were also dark at the same position; they must therefore have a similar orientation. The authors suggest that this might perhaps be used as a means of estimating grain size. Unfortunately, they could not obtain equally good results with finely laminated pearlite, globular cementite, sorbite, troostite, or hardened and tempered structures.

Of the carbides, Cr_7C_3 and Cr_4C, the former is trigonal and the latter cubic. The authors examined samples containing these carbides and found they could be identified with polarised light quite as definitely as by etching with Murakami's reagent.

Tungsten forms two carbides, WC and W_2C, both of which crystallise in the hexagonal system. The grain structure of pure sintered WC and W_2C showed quite definitely when unetched sections were examined in polarised light. Similar examination also enabled sintered hard alloys, consisting of tungsten carbide embedded in cobalt, to be distinguished from similar alloys in which the tungsten carbide was replaced by titanium carbide—the latter being cubic and therefore isotropic.

Attempts were also made to identify the injurious tungsten carbide in wrongly annealed tungsten magnet steel (0·6 per cent. carbon, 6 per cent. tungsten; annealed fifteen hours at 950 deg. Cent.). The authors remark that tungsten carbide is very brittle and easily breaks out during grinding and polishing, but by careful preparation they obtained a polished section in which the tungsten carbide lit up strongly in polarised light and showed definite double refraction, although it did not become very dark during rotation, owing to the reflection of light from the broken off edges, and also probably to the minuteness of the crystals in many cases.

Carbide particles in a steel containing 0·54 per cent. carbon and 9 per cent. vanadium were found to be isotropic. It was assumed that their composition was V_4C_3, and hence the latter must be cubic.

The hexagonal compound $FeSi_2$ is found in iron-silicon alloys, containing about 50 per cent. silicon. A polished sample of an alloy containing 53 per cent. appeared to be completely homogeneous in ordinary light, but between crossed nicols showed an anisotropic constituent which was probably this hexagonal silicide. The other two compounds, FeSi and Fe_3Si, which occur in iron-silicon alloys, are both cubic.

The crystal structure of the inter-metallic compound FeCr is not known with certainty; Eriksson[11] believed that it had a deformed cubic lattice. The authors examined a steel containing about 25 per cent. chromium and 20 per cent. nickel in which this compound and carbide were present in both needle-like and spherical forms. No anisotropy could be detected in polarised light, both compound and carbide remaining dark between crossed nicols. Hence FeCr must have a cubic lattice as Eriksson surmised; the lattice deformation assumed by the latter was too slight to cause double refraction.

According to Hanemann, Herrmann, Hofmann, and Schrader,[12] tetragonal martensite appears light after etching, whereas the cubic form is dark. The authors produced tetragonal martensite in steel containing 1·6 per cent. carbon and 2·5 per cent. manganese by quenching in water from 1100 deg. Cent. and immersing in liquid air; this was changed into the cubic form by annealing for two hours at 150 deg. Cent. Although the light and dark tints of the needles were very definite after etching, the polished samples showed no difference between crossed nicols. Most of the needles in both sections remained dark, only a few—equally numerous in the two sections—being very slightly double refracting, so slight, in fact, as to be scarcely recognisable. It is remarkable, as Schafmeister and Moll state, that the tetragonal and cubic forms show equally weak double refraction. As they point out, however, their similar behaviour could be produced by the distortion of the lattice as a result of infiltration of carbon atoms; this is indicated in both cases by the weakness of the interference lines in X-ray tests, which may be regarded as a tetragonal widening or a general distortion of the normal cubic lattice.

According to H. Masumoto[13] an iron-cobalt alloy containing 2 per cent. iron consisted mainly of hexagonal crystals, only traces of cubic crystals being present, whereas an alloy with more than 5 per cent. iron was almost entirely cubic. When examined in polarised light, the anisotropic phase in a sample of cobalt containing 2 per cent. iron could be identified, but the double refraction observed was very weak. On the other hand, an alloy with 7 per cent. iron was entirely isotropic. Confirmation of these results was obtained by X-ray examination.

In the iron-manganese system, a hexagonal solid solution, the ε-phase, appears between 12 and 30 per cent. manganese. A sample containing 0·06 per cent. carbon and 15 per cent. manganese was heated for fifteen minutes at 1300 deg. Cent., cooled in the furnace to 1000 deg. Cent., held at this temperature for half an hour, quenched in oil, and afterwards annealed for fifty hours at 500 deg. Cent. followed by cooling in air. The ε-phase could be identified without any doubt by X-ray examination, and was also visible, after etching with a 3 per cent. solution of nitric acid in alcohol, as needle-like inclusions in austenite. The needles also showed definite anisotropy when an unetched sample was examined in polarised light.

[11] Jernkont. Ann., 1934, 118, 530.

[12] *Arch. Eisenhüttenwes*, 1930/1931, 4, 479.

[13] Sci. Rep., Tôhoku Univ., Vol. 15 (1936), p. 449.

Detection of Internal Stress.

Ahmad[14] and Schwarz[15] have stated that internal stresses in iron and steel can be clearly detected by polarised light. Ahmad examined samples, which had been cold worked in different amounts and also subjected to elastic stress, with polarised light after they had been etched and stated that the pearlite in stressed areas was brighter under crossed nicols than in other areas not subjected to stress. By way of explanation it was suggested that the deformed zones were more easily etched and as a result had more effect on polarised light.

Schafmeister and Moll point out that it would be very useful to be able to disclose the presence of internal stresses in steel in so simple a manner, and they have endeavoured to confirm Ahmad's results by examining samples with various carbon contents—0·05 per cent., 0·1 per cent., 0·9 per cent., and 1·2 per cent.—in which local deformation had been produced by Brinell impressions. No effect at all could be seen when the unetched sections were examined in polarised light, nor could any difference whatever in brightness be detected between the strongly and lightly deformed areas, in the neighbourhood of the impressions, after the samples had been etched with a 1 per cent. solution of nitric acid in alcohol, as recommended by Ahmad. The same result was obtained on test pieces deformed by bending.

The authors, therefore, conclude that internal stress cannot be detected by polarised light, and they refer to the work of Dayton,[16] who also found no variation in brightness in cold-worked test pieces, and concluded that the etching differences produced were too slight to cause variations in brightness with polarised light. They point out also that the examination of etched surfaces with polarised light can very easily lead to mistakes, due to disturbing reflections which are produced by the roughened surface of an etched sample.

Protective Coatings of Non-cubic Metals.

The authors point out that the microscopical examination of such coatings with polarised light would have a practical significance if extremely thin films of these metals, which could be recognised only with difficulty in ordinary light, were more readily visible in polarised light. They investigated coatings of various thicknesses, of tin, zinc, and cadmium, which had been deposited electrolytically on mild steel and concluded that, although the coatings lit up definitely with polarised light, the method offered no advantage as compared with examination in ordinary light. They mention, however, that the transition layer which is formed during hot galvanising between the zinc and the iron was found to be isotropic. The zinc layer above it, however, lit up definitely in polarised light.

As will be seen, the paper by Schafmeister and Moll is mainly a detailed account of their own observations with polarised light on a great variety of iron and steel samples, and hence, is of considerable value to those who may wish to use this method of investigation. Much of their work is in agreement with that of Hoyt and Scheil and, generally, when they differ from other investigators, they present a good case. In some instances, however, further investigation would appear to be necessary.

[14] *Loc. cit.*

[15] *Z. Metallkunde*, 1932, 24, 97.

[16] "Theory and Use of the Metallurgical Polarisation Microscope." Trans. A.I.M.E., 1935, 117, 119.

Crystallisation, Creep and Age-Hardening of Lead and Antimonial Lead.

During recent years a great deal of research has been directed towards discovering the cause of intercrystalline failure of lead and means for preventing it with the primary object of producing cable sheathing which is not subject to breakdown under vibrational stresses. As the result of this work new alloys have been produced which have a greater resistance to creep and intercrystalline fatigue than ordinary lead; these contain either a small quantity of tellurium or small amounts of tin and cadmium. Additions of very small quantities of other metals, notably lithium and magnesium, have also been found to improve the mechanical properties of lead. Antimonial lead can be hardened by suitable heat treatment, and here, again, the presence of small quantities of other metals exerts a profound effect on the properties of the metal.

In view of these results a comprehensive programme of research into the effect of small percentages of impurities in lead on its properties has been initiated in Australia by Professor Neill Greenwood and his collaborators, and a similar series of researches is being carried out at the Kaiser-Wilhelm Institut für physikalische Chemie und Electrochemie in Berlin. Both groups of workers have already published a series of papers covering a fairly wide field.

Greenwood's preliminary work[1] indicated that lead can fail by intercrystalline cracking under the application of a small, steady stress in air even in the absence of vibration or corrosive media; carefully deoxidised and vacuum-melted lead does not show this behaviour, and Greenwood therefore concludes that the failure is due to oxidation along the grain boundaries, or to the presence of oxide films between the metal crystals. Creep rates of lead at low stresses are very considerably influenced by previous mechanical and thermal history and by very slight changes in composition; thus, either complete removal of all the impurities normally present in the best grades of commercial lead or the addition of small amounts of silver, zinc, bismuth, antimony, or tellurium produces a considerable increase in the creep rate under loads of 500 lb. per square inch. To ascertain the individual effect of the various impurities which may occur in commercial lead, R. S. Russell[2] prepared electrolytic lead containing less than 0·0005 per cent. of impurity and added from 0·0001 to 0·05 per cent. of the above metals separately; the creep rates were then determined. Bismuth has the greatest strengthening effect under stresses of 350 lb. per square inch, but has practically no effect under stresses of 500 lb. per square inch; the other four elements have pronounced strengthening effects at the higher stress even when present in only minute amounts, but at the lower stress their effects are much less marked. Oxygen considerably reduces the rate of creep,

[1] Proc., Austral. I.M.M., 1935, No. 100, 477.

[2] Proc., Austral. I.M.M., 1936, No. 101, 23.

hence, the higher the casting temperature the lower is the rate of creep. Tellurium reduces the grain size, but causes the rate of creep to increase gradually under a steady load and cracks to appear after a 12 per cent. elongation. According to Greenwood and Worner[3] commercial lead containing 0·05–0·10 per cent. of tellurium shows a continuously increasing rate of creep under 500 lb. per square inch, which is greater the higher the tellurium content and the longer the metal is stored after cold rolling; thus commercial lead free from tellurium elongates only 4·5 per cent. in 250 days when tested six months after rolling, whereas after addition of 0·1 per cent. tellurium the elongation under similar conditions reaches 92·5 per cent. after only thirty-two days and the metal breaks. These authors conclude that tellurium is not a suitable addition to lead which is to be used under conditions in which creep can occur.

Tellurium-lead begins to soften two to three days after cold rolling, and the hardness reaches a constant value after 100 days, but with the 0·05 per cent. tellurium alloy a further softening begins after 200 days and proceeds during another 120 days. Complete recrystallisation takes several weeks at ordinary temperature, but only thirty minutes at 60 deg. Cent. Pure electrolytic lead completely recrystallises in five minutes,[4] but the cast metal with 0·05 per cent. of antimony may take up to a fortnight unless it is previously annealed for ten days at 300 deg. Cent. *in vacuo*, when it recrystallises in two hours. Antimony in small amounts has no effect on the grain size of lead.

E. Jenckel and H. Hammes[5] have studied the effect of small additions of various metals on the grain size and hardness of lead. The following table shows the results obtained :—

Group I.

Addition metal, per cent.	Grains per linear centimetre.			Brinell hardness as cast.	Recovery temperature, deg. C.
	Cast metal.	Six months after rolling.	After heating at 180° or 60° C.		
Platinum 0·1	8	100	85	5·9	0
Palladium 0·1	8	108	62	5·9	0
Selenium 0·1	16	105	71	5·0	40
Gold ... 0·1	6	17	12	8·4	40
Barium ... 0·1	6	78	63	5·5	60
Lithium ... 0·02	24	73	61	9·3	80
Potassium 0·1	83	85	65	15·0	80
Sodium ... 0·1	7	89	67	4·9	80
Magnesium 0·1	1	166	143	8·8	80
Calcium ... 0·05	7	123	90	5·5	80
Tellurium 0·06	4	113	60	5·6	120
Calcium ... 0·1	11	263	263	13·0	160
Lithium ... 0·1	4	270	270	15·0	160

Group II.

Pure lead —	4	65	25	5·4	Below 0
Zinc... ... 0·1	4	73	48	4·5	,,
Mercury ... 0·1	8	71	58	4·3	,,
Thallium 0·1	4	68	25	4·6	,,
Tin ... ... 0·1	25	60	28	4·7	,,
Antimony 0·1	3	85	38	4·3	,,
Bismuth 0·1	4	61	53	4·7	,,

[3] Proc., Austral. I.M.M., 1936, No. 101, 57.

[4] Russell, *ibid.*, 23.

[5] *Z. Metallkunde*, 1937, 29, 89.

The metals in Group I all form intermetallic compounds with lead, whereas those in Group II form only limited ranges of solid solutions. It will be seen that the Group I metals alone produce any increase in the recovery temperature,[6] and, with the exception of gold and barium, have a much greater grain-refining effect on the worked metal than the Group II metals; calcium and lithium have the greatest grain-refining effect of any of the metals tested, and their effect persists even after heating above the recovery temperature. In the cases of tellurium and magnesium, the recovery temperature increases with increasing percentage of addition metal; as little as 0·005 per cent. of either element appreciably raises the recovery temperature, which reaches a maximum with about 0·06 per cent., further additions having little effect either way.

According to W. Hofmann, A. Schrader, and H. Hanemann,[7] the Brinell hardness of homogenised and quenched alloys of lead with up to 3·5 per cent. antimony increases almost linearly with the antimony content from 3 to 6; when the alloys are subsequently stored at room temperature the hardness increases with time when the antimony content exceeds about 1·1 per cent., but the rate of hardening and the maximum hardness attained depend on the purity of the lead, alloys made with 99·96 per cent. lead hardening much more rapidly and to a higher value than similar alloys made with 99·99 per cent. lead; thus the alloy with 1·1 per cent. antimony made from the lower grade of lead acquires a hardness of 13·5 in twenty-five days, whereas a similar alloy made from 99·99 per cent. lead takes seventy-five days to acquire a maximum hardness of just over 10. Ageing at 100 deg. Cent. results in a more rapid hardening, but the maximum hardness obtainable is much lower than that obtained at room temperature. The greater hardening effect shown by alloys made from 99·96 per cent. lead has been proved by M. Bluth and H. Hanemann[8] to be due to the presence of small amounts of arsenic and copper in the lead. In the 1 per cent. antimony alloy the presence of 0·05–0·1 per cent. arsenic produces the maximum hardness (13) on ageing, and a similar hardening effect is produced by 0·01 per cent. copper, but the maximum hardness attainable is only 8; the best results are, however, obtained by the simultaneous presence of 0·05 per cent. arsenic and 0·005 per cent. copper.

When antimonial lead is cold rolled immediately after quenching and then stored at room temperature, the hardness increases to a maximum within a few days, and then falls rapidly; in the case of the 2 per cent. antimony alloy with pure lead a maximum hardness of 16·5 is reached in twenty days, but this falls to 12 in eighty days. This effect is much more marked with a similar alloy made from 99·96 per cent. lead, which attains a hardness of 14 in two to three days, and then rapidly softens to a hardness of only 6·5 in sixty days. Alloys with only 1 per cent. antimony undergo little or no age hardening after cold rolling. The decrease in hardness on prolonged storage at room temperature after cold rolling

[6] When cold-rolled lead is heated for one hour at gradually increasing temperatures and the hardness measured on cooling, the curve obtained by plotting the hardness against the temperature descends rapidly at first and then more slowly; the temperature at which the bend in the curve occurs is the "recovery temperature," *i.e.*, the minimum temperature at which the metal recovers from the effects of cold work.

[7] *Z. Metallkunde*, 1937, 29, 39.

[8] *Z. Metallkunde*, 1937, 29, 48.

is due to recrystallisation, which induces coagulation of the precipitated phase into microscopically visible particles. If the cold-worked 2 per cent. antimony alloy is kept at 100 deg. Cent. for a week, precipitation of the excess antimony in the form of small acicular crystals occurs without recrystallisation of the lead matrix. By heating the cold-worked alloys to 100 deg. Cent. for a short time the age hardness decreases slightly, but is subsequently retained at room temperature for prolonged periods, *i.e.*, the short heating treatment prevents subsequent rapid loss of age hardness at room temperature. Similar stability of hardness is obtained by cold rolling after the alloy has fully age-hardened at room temperature, although the actual rolling operation causes a slight reduction of hardness; for example, the alloy with 2 per cent. antimony made with 99·96 per cent. lead acquires a hardness of 15 on storing for three months after quenching, and this falls to 11 after rolling, but no further decrease occurs over a period of several months.

Lead is a valuable metal for studying creep phenomena, since it behaves at room temperature in a similar way to other metals at high temperatures; under a steady stress a constant rate of creep is rapidly set up, and by measuring this rate under a given stress the creep limit can be readily calculated. Tests made by K. von Hanffstengel and H. Hanemann[9] have shown that creep is the resultant of three different processes of deformation, namely, (*a*) elongation by place exchange at the grain boundaries, (*b*) elongation by place exchange produced by recrystallisation and recovery from cold work, and (*c*) elongation by translation along slip planes. Under small stresses or at low rates of creep elongation occurs chiefly by grain boundary deformation, but at higher rates of creep or under greater stresses it proceeds by recrystallisation, recovery, and translation.

Lead and its alloys are very difficult to polish in such a way that the macro and microstructure can be fully developed by etching. A. Schrader and H. Hanemann[10] have recently described a method by which excellent microsections free from scratches can be quite quickly prepared. After sawing off a specimen of the desired size it is polished consecutively in the usual way on emery papers No. 2, 1 F, 00, and 0000, using a liquid wax coating on the papers to prevent inclusions of emery particles during the polishing. The specimen is then polished on a rotating disc running at 600 r.p.m. and covered with a soft cloth impregnated with a dilute suspension of levigated alumina in 0·2 per cent. nitric acid. The final polishing is done by hand on a moist chamois leather coated with a thick, aqueous paste of levigated alumina using only a very light pressure, the surface being occasionally etched and repolished until a perfectly smooth finish is obtained. The etching agent used in this process and also for the final etching to develop the structure is a mixture of 15 c.c. of glacial acetic acid, 15 c.c. of concentrated nitric acid and 60 c.c. of glycerine. A more delicate etch to reveal minute inclusions, such as the precipitated phase in age-hardened antimonial lead, is obtained by diluting the etching solution with twice its volume of glycerine. The original paper contains some beautiful photographs of the structure of antimony-lead, tin-lead, and tellurium-lead alloys in various stages of heat treatment.

[9] *Z. Metallkunde*, 1937, 29, 50.

[10] *Z. Metallkunde*, 1937, 29, 37.

Embrittling Effects of Tempering of Steels.

THE normal effect of tempering a quenched steel is to produce a progressive increase in the impact figure. There are, however, according to L. Guillet and M. Ballay* four types of brittleness of great practical interest which may be produced by reheating the quenched steel below Ac_1.

(1) The reduction of impact figure after a short heating at 100 deg. Cent. is, according to the authors, apparently due to the decomposition of residual austenite. It may occur with or without alteration in hardness, since the action on the austenite is accompanied by a tempering of the martensite.

(2) Above 100 deg. Cent. the curve of impact figure against tempering temperature first rises, but then falls again to a minimum about 350 deg. Cent. This is very pronounced in alloy steels such as nickel-chromium, and the addition of molybdenum does not affect the extent of the fall. The result is that the impact figure of a nickel-chromium-molybdenum steel tempered at 200 deg. Cent. (hardness 553) is considerably higher than that of the same steel tempered at 350 deg. or even at 400 deg. Cent. (hardness 455). The cause of this minimum is not known with certainty. The authors suggest that it is the effect of precipitation of some constituent not yet identified.

(3) Above 350 deg. Cent. the curve again rises, but when the time of tempering is prolonged in the vicinity of 450 deg. Cent. or above, another minimum is encountered. This is the well-known temper-brittleness effect, affecting all steels to a greater or lesser extent, reduced by molybdenum and (the authors state) by tungsten, and minimised by the presence of a very low percentage of phosphorus. They give an example of a nickel-chromium steel containing 0·01 per cent. of phosphorus, the impact figure of which fell less than 10 per cent. after 1000 hours at 500 deg. Cent.

(4) Temper-brittleness is not accompanied by any change in hardness of the steel, but other steels heated in the same range of temperature are subject not only to a fall of impact value, but to a marked increase of hardness, tensile strength, and elastic limit, which distinguishes the phenomenon of temper-hardening from temper-brittleness. An example is given in the behaviour of a chromium-nickel-aluminium-molybdenum nitriding steel (C 0·21, Ni 2·77, Cr 1·13, Al 0·95, Mo 0·44 per cent.), which possessed the following properties:—

	Oil-hardened from 900 deg. Cent.	
	Tempered for 1 h. at 660 deg.	Then re-heated, 65 h. at 500 deg.
Yield point, tons per square inch ...	47·0	71·1
Maximum load, tons per square inch	56·2	75·3
Elongation, per cent.	19	15
Impact figure (Mesnager notch), mkg. per sq. cm.	19·3	5·4
Brinell hardness number	262	360

The same steel without aluminium was not affected in impact figure by heating for sixty-five hours at 500 deg. Cent. The structural hardening in this

* *Comptes Rendus*, June 21st, 1937, 204, 1849.

instance appears to be due to the precipitation of a compound of nickel and aluminium.

It is undoubtedly desirable that the distinctions pointed out should be kept in mind, especially, perhaps, by French writers who have been too apt to use the term *fragilité de revenu* indiscriminately for all types of brittleness induced by reheating. It may be that the first group is treated rather too narrowly by the authors, since strain hardening and strain embrittlement also are enhanced by treatment at 100 deg. Cent., and internal quenching stresses may be sufficient to account for the effect without assuming the presence of austenite which, in some steels at least, which show a fall of impact figure after heating at 100 deg. Cent., is unlikely to be retained by quenching.

The Effect of Gases on Metals.

THE method of extracting gases from metals by making the metal specimen the cathode in an evacuated discharge tube* provides a means of investigating the effect produced solely by the removal of gas, since it enables all, or nearly all, the gas to be extracted from a metal without appreciable rise of temperature. The method has been employed by its originators, Messieurs A. Portevin, G. Chaudron, and L. Moreau, to the study of the effect of gases in electrodeposited iron and other metals.†

A metal produced by electrodeposition is usually much harder than the same metal in the annealed condition. The lines of the X-ray spectrum are broader and the electrical conductivity is lower in the electrodeposited metal, effects which are the accompaniments of distortion of the crystal lattice and a very fine grain size. Cold working may produce results of a similar kind.

The three investigators have studied the variations in hardness, conductivity, and lattice parameter after removal of gas without appreciable rise in temperature, after reheating, and in other instances after charging the metal with hydrogen electrolytically.

The results obtained with electrolytic iron (Table I) led to the following conclusions :—

(1) The elimination of hydrogen does not modify the hardness or the lattice parameter, and the diffuse character of the lines of the X-ray spectrum is retained.

(2) Annealing causes restoration of the lattice with a notable decrease in hardness, but this occurs without any pronounced evolution of gas. The lattice shrinks and the lines of the spectrum become very sharp.

From these the authors deduce that hydrogen is not the effective or immediate cause of the hardening, but that the presence of a sufficient amount of hydrogen may be an initial or primary cause in that it may induce some special type of deformation in the lattice of the electrodeposited metal.

The inverse effect was studied by charging an Armco iron wire with hydrogen by electrolysis. When the hydrogen content was upwards of about 100 c.c. per 100 g. the elongation was reduced and the resistivity increased (Table II), and this change persisted after degassing. In other words, the temporary insertion of hydrogen atoms had a similar influence to cold work, and after removal of the hydrogen without rise in temperature the effect still remained.

TABLE II.—*Iron Wire Charged with Hydrogen Electrolytically.*

E = elongation per cent. ; ρ = resistivity (microhm-cm.).

Initial condition :	
E, per cent.	25
ρ	10·9
Vol. H_2, initial	68·8
Charged with hydrogen :	
E, per cent.	7·2
ρ	11·09
Vol. H_2 removed	150
Degassed :	
E, per cent.	7·2
ρ	11·2

TABLE I.—*Electrolytic Iron (Hardness and Lattice Parameter).*

No.	Before degassing.			Vol. H_2, c.c. per 100 g.	After degassing.			After reheating.		
	Brinell hardness number.	Å.	$\frac{l}{h}$		Brinell hardness number.	Å.	$\frac{l}{h}$	Brinell hardness number.	Å.	$\frac{l}{h}$
1	470	$2·859_2$	1·2	307	475	$\left\{\begin{matrix}2·859_4\\2·859_6\end{matrix}\right\}$	0·8	120	$2·858_8$	0·5
2	—	$2·856_9$	1·3	—	—	$2·857_3$	1·0	—	—	—
3	$\left\{\begin{matrix}175\\180\end{matrix}\right\}$	$2·861_8$	0·9	223	$\left\{\begin{matrix}175\\180\end{matrix}\right\}$	$\left\{\begin{matrix}2·861_8\\2·862_3\end{matrix}\right\}$	0·8	110	$2·860_8$	0·4

$\frac{l}{h}$ is a coefficient expressing relative breadth of the lines of the X-ray spectrum.

A metal produced by electrodeposition is usually much harder than the same metal in the annealed condition. The lines of the X-ray spectrum are broader and the electrical conductivity is lower in the electrodeposited metal, effects which are the accompaniments of distortion of the crystal lattice and a very fine grain size. Cold working may produce results of a similar kind.

The three investigators have studied the variations in hardness, conductivity, and lattice parameter after removal of gas without appreciable rise in temperature, after reheating, and in other instances after charging the metal with hydrogen electrolytically.

The results obtained with electrolytic iron (Table I) led to the following conclusions :—

(1) The elimination of hydrogen does not modify the hardness or the lattice parameter, and the diffuse character of the lines of the X-ray spectrum is retained.

(2) Annealing causes restoration of the lattice with a notable decrease in hardness, but this occurs without any pronounced evolution of gas. The lattice shrinks and the lines of the spectrum become very sharp.

From these the authors deduce that hydrogen is not the effective or immediate cause of the hardening, but that the presence of a sufficient amount of hydrogen may be an initial or primary cause in that it may induce some special type of deformation in the lattice of the electrodeposited metal.

The inverse effect was studied by charging an Armco iron wire with hydrogen by electrolysis. When the hydrogen content was upwards of about 100 c.c. per 100 g. the elongation was reduced and the resistivity increased (Table II), and this change persisted after degassing. In other words, the temporary insertion of hydrogen atoms had a similar influence to cold work, and after removal of the hydrogen without rise in temperature the effect still remained.

The authors were able to show in a qualitative way that a similar effect was to be observed in aluminium wires, but reserved a fuller discussion of this for a future memoir.

The Attack of Heat-Resisting Steels by Hot Gases.

AMONG the papers on oxidation and corrosion of steels at high temperatures presented at the recent Congress of the International Association for Testing Materials, in London, was one by E. Houdremont and G. Bandel, in which they pointed out that the successful development or correct choice of a heat-resisting steel is dependent on a knowledge of the reactions which govern the attack of the steel by the individual gases present, and on a study of the formation of the scale, its structure, and the changes in its properties which may be brought about by the

* THE METALLURGIST, 1935–36 (Oct., 1935), 10, 71.

† *Comptes Rendus* (April 26th), 1937, 204, 1252.

diffusion of alloy elements outwards and of oxygen and the products of combustion inwards.

The work of these authors has been described in greater detail elsewhere,* particularly with reference to the practical question of the provision of suitable steels for corrosion resistance against various hot gases used or encountered in industry.

The alloy elements added to steel can be classified in two groups according to their affinity for oxygen in comparison with that of iron. In one group are copper, nickel, cobalt and molybdenum, and in the other chromium, silicon, aluminium, titanium, &c. Scaling resistance is obtained through those of the second group, which favour the formation of a protective layer on the surface of the steel.

An effective protective layer must have good mechanical adhesion, a self-healing capacity and at the same time considerable resistance to the diffusion of oxygen inward or of the alloy elements outward.

EFFECT OF VARIOUS GASES.

In experiments with air and steam the principal feature emphasised by the experimental results was the unfavourable behaviour of the 1 per cent. chromium-silicon steel in comparison with that of 2·5 to 6 per cent. chromium-silicon steels. Carbon dioxide exerted a somewhat stronger attack than air. Carbon monoxide forms volatile carbonyls over the range 100 deg. to 300 deg. Cent. and 50 to 70 atmospheres pressure. At normal pressure and high temperature carburisation occurs, but this effect is masked in technical gas mixtures by the presence of oxidising or strongly decarburising gases. Hydrogen at 400 deg. to 600 deg. Cent. and 100 to 1000 atmospheres pressure has an extremely damaging effect, decarburising, causing brittleness, and giving rise to blisters containing methane, though 6 per cent. chromium steel containing titanium or vanadium is said to be immune from this attack. Under normal pressure the decarburising effect of hydrogen was not found to be dangerous. Sulphur dioxide exercises a strongly oxidising effect, but the sulphur which it contains can, especially with steels of high nickel content, form fusible sulphides and eutectics which undermine the protective layers. Such products are :

	Melting point, deg. Cent.
Ferrous sulphide, FeS	1190
Nickel sulphide, NiS	797
Aluminium sulphide, Al_2S_3	1100
Eutectic, Ni-Ni_3S_2 (22 per cent. S)	645
„ Fe-FeS (31 per cent. S)	985

Hydrogen sulphide has a very powerful action, and resistance to attack is not secured until the chromium content of the steel exceeds 12 per cent., irrespective of the amount of nickel present. The addition of aluminium in amounts not less than 5 per cent., as well as silicon, leads to improvement.

Carburising, decarburising, and nitriding processes (the latter arising from the presence of ammonia) may have a pronounced effect on the course of scaling. In a chromium steel carburisation may lead to impoverishment of the ground mass in chromium and thus to a reduction in resistance to scaling. Decarburisation or carburisation may cause undesirable changes in structure (owing to the $\gamma \rightleftarrows \alpha$ transformation) as a result of which a wide zone of columnar crystals may be formed, giving an easy path for intercrystalline penetration. Atmospheric nitrogen may exert a direct action on 20–30 per cent. chromium steels. In a steel of this type a nitrogen absorption of 0·5 per cent. was found to have taken place after 500 hours' exposure at 1200 deg. Cent. A ferritic steel may become austenitic at the surface owing to absorption of nitrogen, and austenitic regions were observed to appear in the interior of a ferritic chromium-silicon steel in which enrichment of nitrogen had occurred. In chromium-aluminium steels surface absorption of nitrogen, forming AlN, may cause a diminution of the aluminium content of the protective layer with consequent loss of resistance to scaling.

The authors conclude with a table of compositions of heat-resisting steels and alloys which have been found useful up to certain specified temperatures in air. Their insistence on the necessity for studying the underlying processes of scale formation is probably the most important aspect of their work. It has been recognised by investigators of the subject in this country, particularly by Professor Cobb and his associates at Leeds, that a study of the structure and mechanism of scale formation is an essential part of any research on heat-resisting steels. The interim report on "Scaling of Steels in Sulphur-free and Sulphur-containing Furnace Atmospheres" contained in the First Report of the Alloy Steels Research Committee, shows that this aspect of the subject is receiving attention.

* E. Houdremont and G. Bandel, *Jernkontorets Annaler*, 1937, 121, 64.

The Constitution of Manganese Steels.

IT is evident from many published researches on the influence of manganese on the structural and mechanical properties of the iron-carbon alloys that there is often some difficulty in ascertaining equilibrium conditions on account of undercooling due to the retarding effect of manganese on thermal transformations and processes of diffusion. Lack of agreement in data about the transformations in the iron-rich iron-manganese alloys is clearly revealed in the account given in W. Hansen's recent book on binary alloy systems.[1] Only a few researches have been made on the manganese-carbon alloys, but the suggested interpretations of the constitution of these alloys differ widely from one another. The best information about the ternary system is the general summary published by F. M. Walters, jun., and C. Wells as Part XV of the research on "Alloys of Iron, Manganese, and Carbon."[2]

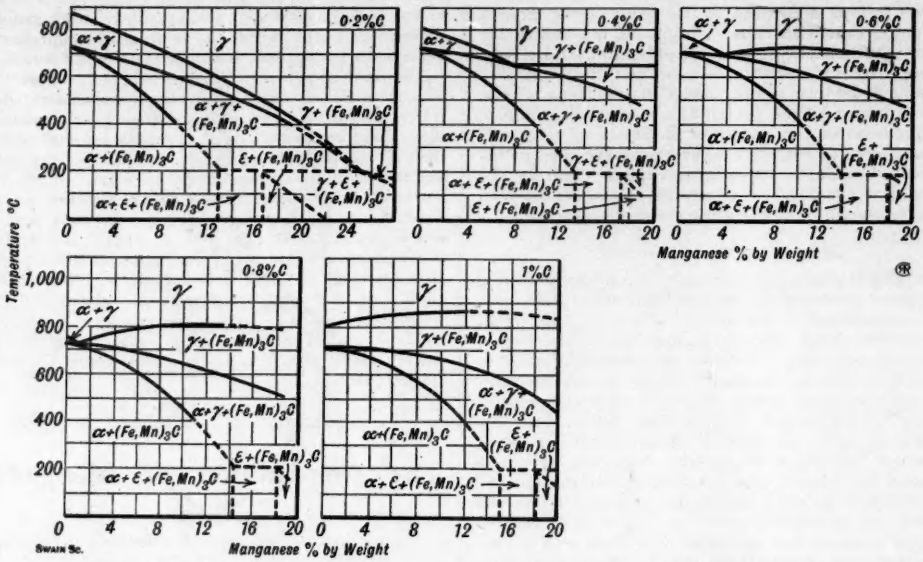
In a paper on "The Transformations in the Solid State of Manganese Steels Containing up to 1·2 Per Cent. of Carbon and 17 Per Cent. of Manganese," W. Tofaute and K. Linden[3] have constructed from published data a series of sections through the iron-manganese-carbon equilibrium diagram along planes of constant carbon content and of constant manganese content and have also indicated the conditions of equilibrium at temperatures between 400 deg. and 700 deg. Cent. by sections at constant temperatures. The diagrams derived in this way are reproduced in Figs. 1 to 16. The critical ranges corresponding to the A_1 and A_3 points of the iron-carbon alloys are depressed by increasing manganese content (Figs. 1 to 5), while with constant manganese content the A_1

[1] "Der Aufbau der Zweistofflegierungen," Berlin, 1936, p. 676.

[2] "Trans.," Amer. Soc. for Metals, 1936, 24, 359–374.

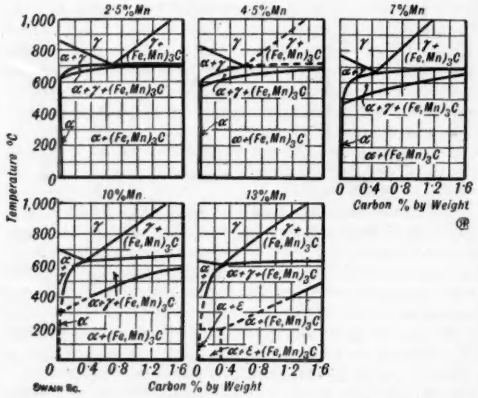
[3] *Archiv für des Eisenhüttenwesen*, May, 1937, 1936/37, 11, 515–524.

point is raised by increasing carbon (Figs. 6–10). The sections at constant temperature (Figs. 11–16) are of particular interest. They show that in the range 400 deg. to 700 deg. Cent. there is, even at a low manganese content, a two-phase field containing a manganese-poor α and a manganese-rich γ solution, by these constant-temperature sections is that the boundary between the two-phase region $\alpha+(Fe,Mn)_3C$ and the three-phase region $\alpha+\gamma+(Fe,Mn)_3C$ is displaced to a higher manganese content as the carbon content increases. On account of the isomorphous replacement of iron by manganese, an increase in the



FIGS. 1 TO 5—*Sections Through the Iron-manganese-carbon System at Constant Carbon Contents.*

the manganese contents of which become more widely different as the temperature is lowered. These sections help to explain the variation in observed temperature of transformation which can result from differences in heat treatment of the steel. Since an alloy with no more than 5 per cent. of manganese



FIGS. 6 TO 10—*Sections through the Iron-manganese-carbon System at Constant Manganese Contents.*

contains, at 650 deg. Cent., a manganese-rich γ phase with 12 per cent. of manganese, the tendency to undercooling when the alloy is cooled slowly to atmospheric temperature is explained. Another point illustrated amount of cementite present involves also an increase in the amount of manganese which may exist as carbide. Tofaute and Linden tried to examine by X-ray analysis the structure of the carbides separated from the steels containing manganese by Maurer and Hartmann's method.[4] They found, however, that decomposition had occurred, and the examination showed graphite in the residue, though there was, of course, none present in the original steel. This might have been expected. The work of Arnold and Read[5] proved that manganese carbide was readily decomposed by acids, and oxidised in the air, unless special precautions were taken.

After producing these diagrams the authors carefully correlated their indications with certain characteristics of the steels such as magnetic saturation value, electrical resistivity, thermal expansion, hardness, and mechanical properties.

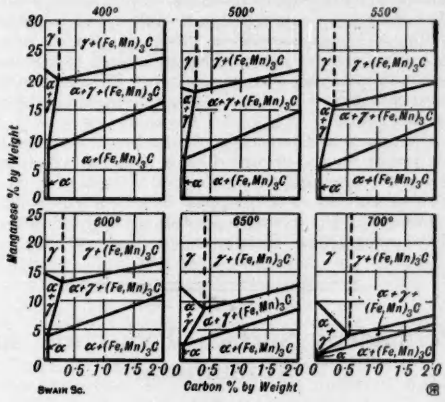
For this purpose several series of alloys were made in 5 kilo. melts in the basic high-frequency furnace. These had a range of composition from 0·028 to 1·19 per cent. carbon and 2 to 17 per cent. manganese with 0·05 to 0·72 per cent. of silicon. The specimens were annealed for fifteen minutes at 1300 deg. Cent., quenched in oil from 1000 deg. Cent., reheated at the required tempering temperature for fifty hours, and cooled in air.

The saturation value of the magnetic induction in a field of 10,000 oersted was the main property studied, as this gives a direct indication of the relative amounts of the α and γ phases present. In the

[4] *Zeit. anorg. Chem.*, 1924, 136, 75.

[5] *Journ.*, Iron and Steel Inst., 1910 (1), 169.

carbon-free iron-manganese series the saturation value of the magnetic induction was very low for the 15 per cent. manganese alloy, whatever the temperature of tempering. With 9 per cent. of manganese it fell to a minimum indicating the presence of about half and half ferrite and austenite (*i.e.*, $\gamma+\varepsilon$, since ε is also non-magnetic). This minimum occurred after tempering at 600 deg. Cent., and then the magnetic saturation rose again to its original value after tempering at 650 deg. and 700 deg. Cent. On reference to Figs. 11 and 12 it will be seen that a γ solid solution appears, the manganese content of which is so high that air cooling from the tempering temperature is sufficient to retain it as austenite. With increasing tempering temperature the amount of γ increases, and at the same time the manganese content of the austenite is reduced. As a result the magnetic saturation value is first diminished, but begins to recover again when the manganese content of the austenite becomes so low (below 12 per cent.) that the rate of cooling in air is slower than the critical cooling velocity. From this tempering temperature upwards the saturation value rises, since the

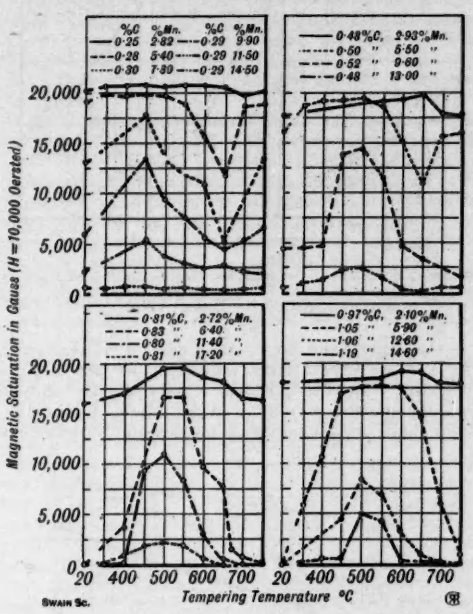


FIGS. 11 TO 16—*Sections through the Iron-manganese-carbon System at Constant Temperatures.*

austenite present at the tempering temperature transforms during cooling to ferrite and martensite.

That the behaviour is modified by carbon content as well as by manganese content is shown by the results represented in Figs. 17 to 20. These also are in accordance with the phase diagrams (Figs. 11 to 16). The 0·28 per cent. carbon steel with 5·4 per cent. of manganese behaves similiarly to the carbon-free 9 per cent. alloy described above. In general, after oil cooling from 1000 deg. Cent., the magnetic saturation has a lower value the higher the carbon and manganese content. The first rise on tempering is due to the transformation of retained austenite to martensite. The formation of gradually increasing amounts of austenite as the temperature of tempering rises to 700 deg. Cent. causes a fall in magnetic saturation values. The subsequent rise, which only occurs in steels which fall within the $\alpha+\gamma$ region at 650–700 deg. Cent. (Figs. 15 and 16), is due to the low manganese content of the austenite which permits transformation to ferrite and martensite during air cooling.

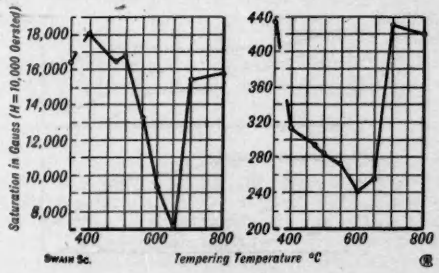
Electrical resistivity was found to give a similar indication, and except that the Brinell hardness number falls at a lower tempering temperature, the hardness curve follows the magnetic saturation curve fairly closely in general outline. Figs. 21 and 22, for example, show the magnetic saturation and the Brinell hardness of a steel containing 0·18 per cent. of carbon and 7·47 per cent. of manganese, oil-quenched from



FIGS. 17 TO 20—*Effect of Tempering on the Saturation Values of Magnetic Induction of Manganese Steels (Specimens Annealed for One-quarter of an Hour at 1300 deg. Cent., Oil-quenched from 1000 deg. Cent., Tempered for Fifty Hours and cooled in Air).*

1000 deg. Cent. and reheated at various temperatures. The values were not much affected by raising the quenching temperature to 1250 deg. Cent.

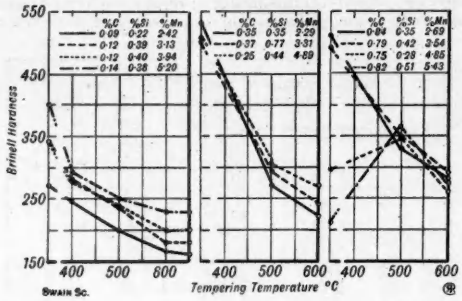
The mechanical properties of the steels were studied in three series of alloys with about 0·12, 0·32, and



FIGS. 21 AND 22—*Effect of Tempering on the Magnetic Saturation Values and Brinell Hardness Numbers of Specimens Containing 0·18 per Cent. Carbon and 7·4 per Cent. Manganese, Oil-quenched from 1000 deg. Cent.*

0·8 per cent. of carbon, and 2·4 to 6·4 per cent. of manganese. This part of the work was thus confined to the pearlitic and martensitic steels, and was not extended to the typical austenitic variety of manganese steel. The results of Brinell hardness

tests on water-quenched and tempered steels are shown in Figs. 23 to 25, and give an approximate idea of the effect of manganese on tensile strength. At low carbon content the effect is relatively large;



FIGS. 23 TO 25—*Effect of Tempering on the Brinell Hardness of Manganese Steels, Water-quenched from 900 deg. Cent. Tempered Eight Hours, and Cooled in Air.*

on the other hand, at medium carbon content (0·32 to 0·8 per cent.) after tempering at 500 deg. to 600 deg. Cent. the hardness is only slightly affected by manganese content. After these preliminary tests had been made full tensile and notched-bar

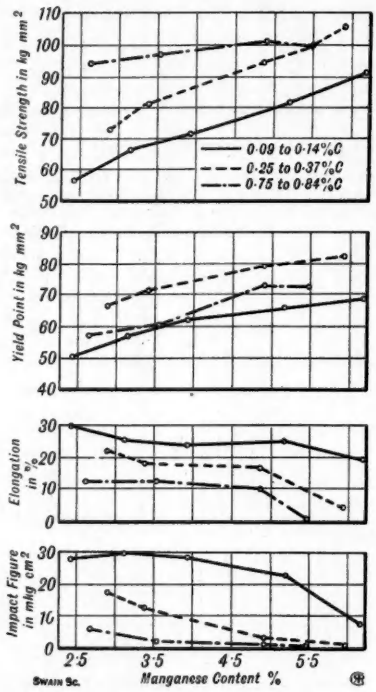


FIG. 26—*Effect of Manganese Content on the Mechanical Properties of Steels, Oil-quenched from 900 deg. Cent., Tempered Eight Hours Below the A_1 Point and Cooled in Oil.*

impact tests were carried out on the steels oil-hardened from 900 deg. Cent. and tempered for eight hours at various temperatures below A_1. Typical results are summarised in Fig. 25 in which it is shown that, for alloys with 0·12 per cent. of carbon, the tensile strength increases almost linearly with manganese content, and may be raised from 50 kilos. to 90 kilos. per square millimetre (31·7 to 57·2 tons per square inch) by increase of manganese from 2 to 6 per cent. The yield ratio was good, the elongation remained at over 20 per cent., and the impact figure did not fall below 20 mkg. per square centimetre until manganese exceeded 5 per cent. In the steels containing about 0·32 per cent. of carbon there was also an appreciable rise in tensile strength, but elongation and impact figure fell considerably below those of the steels of the first group. The alloys of the third group, containing about 0·8 per cent. of carbon, showed little increase of strength with increase of manganese, and elongation and impact figure fell to very low values. The effect of manganese is due not merely to its action on the γ solid solution, but also to the reduced tendency to agglomeration shown by particles of manganiferous cementite.

The utility of the results of the mechanical tests is limited by the fact that no information is given about the size of the specimens treated. Even the behaviour of steels relative to one another is largely influenced by the size of specimen employed, especially when they are as susceptible to differences in rate of cooling as these manganese steels are shown to be. Like the magnetic data, the mechanical test results are chiefly of value for the assistance they give in the interpretation of equilibrium relations displayed by the diagrams.

The diagrams themselves should be of considerable interest to those concerned with the heat treatment of steels containing manganese or interested in their development, since they appear to give a trustworthy summary of the present position of our knowledge of the constitution of these steels.

Permanent Surface Protection for Aluminium.

By D. C. MANDEVILLE.

THE TECHNIQUE OF THE ANODISING PROCESS.

THE majority of the alloys of aluminium are more rapidly corroded than the parent metal itself. It is therefore evident that some form of protection is needed, other than the naturally occurring oxide film, particularly for alloys used for structural purposes in exposed positions and for vessels to be used in connection with saline liquids. Nor is this need for protection confined to alloys only; the pure metal itself is easily corroded by sea water and other similar agencies. The figures in Table I indicate the extent of the corrosion brought about by agitation with a 5 per cent. solution of salt for prolonged periods.

TABLE I.

Material.	Loss per sq. m. surface in 100 hours, grammes.
Pure aluminium, hardened...	0·132
Alloys :	
Silumin	0·670
Lautal	0·196
K.S.S. (resistant alloy)	0·024

Considering its high chemical reactivity, exemplified in the Thermite reaction and in its amalgam, which easily decomposes water, it is remarkable that aluminium is as stable against atmospheric attack

as it is. The explanation lies, of course, in the tenacious, relatively thick film of oxide that is at once formed when any fresh surface is exposed to the air, and to a certain extent inhibits further attack.

Any process that will replace this unsatisfactory film by one more impervious to the most common corrosive agencies is bound to be of the greatest importance industrially, owing to the steady increase in the use of aluminium and of its alloys, notably in aircraft and in all other forms of transport, in electric power transmission, in household, dairy and factory containers and utensils, and as an architectural and structural material generally.

TYPES OF PROTECTIVE COATING.

Three types of protective coating are in general use, viz.:—(1) Paint, varnish, enamel; (2) other metals, either electrodeposited or sprayed; (3) an artificial oxide, thicker than that occurring naturally, and formed either electrolytically (anodisation) or chemically.

In the present article it is proposed to deal only with the third of these types, the artificial oxide film; but a few remarks about the first two of these may not be amiss. The first type of coating may, of course, have almost any desired colour and finish and be reasonably long-lasting; but since it is non-integral with the metal, it will eventually age, chip or blister, and have to be replaced. There is also an objection on purely architectural grounds, that it obscures the metallic nature of the support. Metallic coatings, on the other hand, incur two technical objections: firstly, that it is very difficult, particularly in the electrolytic bath, to eliminate the natural oxide film on the aluminium and so to ensure a really adherent deposit; secondly, that unless the coating is absolutely complete and non-porous (which is unlikely), any galvanic action that occurs in the interstices will cause the dissolution of the aluminium rather than of the metallic coating. In spite of these objections, both types of protection are extensively used.

Oxide coatings are remarkably resistant to abrasive action, imparting to the metal a surface hardness between those of mild steel and of corundum. The film is integral with the surface on which it is formed, the relationship being analogous to that of the glaze on porcelain, and it can be dyed any desired colour with organic or inorganic colouring matter. The particular sheen obtainable (due to metallic reflection through the transparent coloured film) is unique; though a dull finish is also possible. While the thickness of the natural oxide coating on aluminium has been estimated at 10^{-5}in., artificial films several thousandths of an inch thick may be prepared, and these give complete protection against sea water, acid foodstuffs, atmospheric attack, and many chemical reagents. The film is an electric insulator, and dielectric strengths up to 4000 volts are obtainable with the hardest films; but the softer, more ductile coatings are the worse insulators. The film is heat-resistant, in fact the aluminium may by skilful manipulation be melted inside it, collecting at the bottom as in a bag. There are four methods of industrial importance for preparing these artificial oxide films; of these, the first three are electrolytic (anodisation), and the fourth is purely chemical.

CHROMIC ACID PROCESS.

This, the earliest of the processes now in use, dates from a patent taken by Drs. Bengough and Stuart in 1923 for the protection of duralumin seaplane parts from corrosion by sea water. Although it may be applied to aluminium itself and to most other alloys, provided that they contain less than 5 per cent. of copper, it is of importance only as the best process for protecting duralumin.

Anodising processes in general involve three steps: (1) the preliminary treatment (polishing, degreasing); (2) the anodic treatment proper; (3) "sealing" the film to give it enhanced resistance. The third stage is omitted if anodisation is to serve merely as a primer for paint.

The first step is essential, for all irregularities of the surface are accentuated in the anodised film; grease interferes with the formation of the film, rendering it non-adherent. Polishing may be carried out with a variety of methods and of abrasives; in general it requires more skill than with the harder metals; but with all available skill the chromic acid method remains unsuitable for castings which must be treated by one of the other methods. Grease is removed by treatment with trichlorethylene, first in a vapour degreaser, then by immersion, followed by rinsing and drying.

The work is now transferred to the anodising bath, of 3 per cent. chromic acid solution maintained at a temperature of 40–45 deg. Cent. The anodising process liberates heat, and for this reason cooling coils through which water can circulate surround the bath. The cathode is of graphite or of stainless steel, and need not conform to the anode in shape (as in plating baths), but is at least as large. Adequate ventilation must be arranged, since the acid vapours given off during the process are dangerous to operatives. Direct current is used, the current density for pure aluminium being 2½–4 amperes per square foot, and up to 50 amperes per square foot for alloys containing copper. The voltage is gradually raised, from 0 to 40 volts, at which value it remains some time, then further to 50 volts; the total time taken being 1 hour. The process must therefore be worked in successive batches, which is a serious disadvantage.

After rinsing and drying, the film, which is light grey in colour and opaque, is normally sealed by treatment with a solution of lanoline in trichlorethylene, thus filling the pores and considerably increasing its resistant properties.

The process is worked in this country under licence from the Department of Scientific and Industrial Research. Its commercial importance, apart from the use for duralumin seaplane parts, is declining, both here and on the Continent. The average power consumption is 0·2 kWh per square foot.

SULPHURIC ACID PROCESS.

This process, dating from a patent taken by Dr. Gower in 1927, is by far the most widely used in England and in America; though on the Continent and in Japan the oxalic acid process is still a competitor. It has the advantage over the other methods that the films produced are perfectly colourless and transparent, and the power consumption is less. Every sort of work can be treated, wrought and cast, in almost every aluminium alloy, by careful variation of the composition of the electrolyte; an addition of other acids, *e.g.*, acetic, oxalic, may be necessary. No dangerous fumes are evolved.

Sheet metal, particularly if it has been worked in any way, requires polishing before treatment; so do extruded sections. There is, however, an "anodising quality" sheet aluminium now available, which

requires none. Most castings give good results, provided there is no undue porosity after polishing. Degreasing is usually effected in an alkali bath, though this is sometimes preceded by vapour degreasing with trichlorethylene.

The sulphuric acid content of the anodising bath has been varied from 7 per cent. to 77 per cent., and the temperature over a similarly large range; but a typical treatment would employ about 12 per cent. acid at room temperature (20–22 deg. Cent.) for ten to fifty minutes, according to the film thickness required, the voltage employed being 10–20 volts D.C. Glycerine is sometimes added.

A factor to which considerable attention has been paid is the porosity of the oxide film. Too open a film lacks corrosion resistance, while a tight film shows "crazing" of the surface on exposure to temperatures of 200–300 deg. Cent., owing to the unequal expansion of film and metal; cracks are also formed at quite low temperatures in the metal itself, seriously diminishing its tensile strength. A 25 per cent. porosity appears to be most satisfactory.

The film may be dyed by immersion in a warm dye bath, acid colours of the alizarin type being normally employed, for which aluminium oxide itself has a certain mordanting power. More permanent effects are obtainable with certain metallic acetates, *e.g.*, a mixture of cobalt and nickel acetates used as mordants and sealing compounds. The light-fastness of the coloured film depends on the dye used, and for this reason it is often preferable to use inorganic pigments. Prussian blue, for example, may be precipitated in the pores of the film by successive immersions in ferric chloride and in ferrocyanide solutions.

Sealing is effected by several methods: (1) impregnation of the film with lanoline, paraffin, linseed oil, &c.; (2) simple boiling with water, which effects a lamination of the surface, closing all the pores; aluminium reflectors treated by this method may be immersed in a dye bath and take no stain; (3) treatment with potassium dichromate, which renders the surface impervious to sea water; (4) impregnation of the surface with sodium silicate.

The thickness of the coating employed determines the light-reflecting and the insulating properties. Thin films give specular reflection (on polished metal) and weak insulation; thick films diffuse reflection and high insulation (on aluminium and aluminium-silicon alloys only). Flexible films are prepared by operating the anodising bath at a temperature of about 90 deg. Cent.; sheets so coated may be stamped and pressed into various shapes without damage to the oxide film.

The processes employing sulphuric acid as anodising agent in England are the Alumilite, Dialumin, and Sheppard's process. The power consumption is 0·05 to 0·2 kWh per square foot.

OXALIC ACID PROCESS.

This is the latest of the three main processes dating in fact from 1928. It is somewhat more expensive than either of the others to operate, and gives a yellowish or golden opaque film; but there is a certain saving in capital cost, owing to the fact that A.C. may be employed. The electrolyte is dilute oxalic acid, with addition of a small quantity of an oxidising agent such as chromic acid or potassium permanganate. Voltages of from 30 to 100 volts, according to the type of coat, and operating times of from ten to one hundred minutes, according to the thickness required, are employed.

A peculiar phenomenon, seldom perceptible in the other processes, is the intermittent or continual luminescence of the anode, which is often quite clearly visible in the dark, and may be photographed. The light emitted in this fashion appears to have a continuous spectrum, with a maximum round about 4590 Å.U.

Polishing and sealing, the preliminary and final treatments, are similar to those already described. The process is known on the Continent under the name "Eloxal," and is hardly worked in England at all. The power consumption is considerable, but with pure aluminium under the most favourable conditions it may be reduced to 0·4 kWh per square foot. As it has been estimated that 80 per cent. of the cost of anodising is labour, and that the remaining 20 per cent. covers materials, power, and all overheads, it will be clear that this rather high power consumption does not necessarily render that process uneconomic to work.

Although similar in the use of an electrolytic bath, the process of anodising differs from electro-plating in several important respects. In the first place, the oxide films grow from the surface inwards, at the expense of the metal object itself; and as it is no more bulky than the metal, except perhaps in the initial stages, the final dimensions of the anodised article do not differ from those to which it was originally machined, a very satisfactory result in the manufacture of precision work and one that might have been taken to heart by a certain firm of automobile manufacturers, who machined their pistons after anodisation instead of before, and only realised later, when several thousand pistons were already on the road, that they had scraped all the anodisation away by so doing! Secondly, the film is an electric insulator, and cannot therefore be made to grow indefinitely; the current density in all processes drops very rapidly from its initial value till finally a state is reached where the rate of growth due to the much enfeebled current is balanced by the rate of dissolution in the acid of the bath. It is obviously uneconomic to proceed beyond this point.

The hardness of the oxide film varies with the distance from the surface; superficially it is comparatively soft, and the hardest layers of all are those next to the surface of the metal. The figures in Table II are for relative hardness by the Bierbaum test, in which the width of the scratch made by a weighted diamond point is measured.

TABLE II.—*Relative Hardness.*

Aluminium ...	80	Oxide film on Al	Hard finish.	Soft finish.
Razor steel ...	1550	Face of film	140	180
Glass	2000	Centre of film	3000	1200
Chromium ...	3100	Base of film	5000	1550

A CHEMICAL PROCESS.

The M.B.V. process, 1930, is a modification of an old method of Bauer and Vogel, and is purely chemical in operation. It has the advantages of low cost, rapidity and simplicity. Moreover, the articles to be treated do not need to be specially cleaned beforehand, this being effected by the alkali present in the bath. The resulting film, however, is thin and not very resistant, and of a greyish colour. The process is therefore not much used, and it is inapplicable to alloys containing copper.

The M.B.V. bath normally contains about 5 per cent. sodium carbonate and 1·5 per cent. sodium chromate (calculated anhydrous) and is held at a temperature of nearly 100 deg. Cent. Coating is effected merely by immersion in this bath for five minutes, though the bath remains effective down to 2½ per cent. of its original strength, when the operation requires twenty-five minutes. In this way 1 gallon of liquid is sufficient to treat 16 square yards of surface and the cost of treatment is less than ¼d. per square yard. The M.B.V. film is often reinforced by dipping in a solution of sodium silicate, followed by a heat treatment.

The process may also be worked (though more slowly) at a lower temperature, if caustic soda is added to the bath. A cold paste of the same constituents is useful for local application, particularly to the bare points left by the clamping screws during anodic treatment, which cannot otherwise be covered.

REFLECTORS, PISTONS, PHOTOGRAPHY.

Dealing first of all with the more technical applications of the processes, an important recent use of anodised films is in the production of aluminium reflectors for searchlights and motor headlights. The metal surface is electrolytically polished by being made the anode in a warm bath containing sulphuric or chromic acid together with a fluorine compound, high current densities being employed. It is then immediately transferred to a sulphuric acid bath, where it is given a moderately thin oxide coating. According to another process, the first bath contains sodium carbonate and phosphate and the second acid sodium sulphate. In a particular case the reflectivity of an aluminium surface was raised during the brightening process from 75 per cent. to 87 per cent., and the subsequent anodisation only reduced it by 2½ per cent. Such reflectors compare very favourably with polished silver, chromium, and stainless steel, and are completely protected by their oxide film from atmospheric corrosion.

Pistons for internal combustion engines are now being produced by a number of large firms in anodised aluminium. The advantages claimed are twofold. In the first place, corrosion of the cylinder walls is reduced, it being stated in explanation that this is largely electrolytic in origin, and is therefore prevented by the insulating properties of the oxide film. Secondly, it is possible to impregnate the film with a solid lubricant containing graphite, which enhances the efficiency of the lubricating oil employed, and imparts considerable oil-retaining properties to the piston surface.

Among the minor technical applications of anodisation must be mentioned the light-sensitive films formed by deposition of silver salts in the pores of the oxide coating; the product being in effect an aluminium-backed photographic plate, which can be developed, fixed and toned according to normal photographic procedure, and is remarkable for the fine grain and great sensitivity exhibited at the violet end of the spectrum owing to the absence of gelatine.

Anodisation affords complete protection of the surface against solutions containing no mineral acids or strong alkalies, and vessels so treated are finding increasing application in the dairy, laundry, brewing, and canning trades. The process also may be employed as a "primer" for paint, while electroplating of copper and brass on aluminium has been successfully carried out, in which anodisation was a preliminary step.

A considerable amount of research work is in progress with a view to forming oxide coats on aluminium wires suitable for insulating purposes in the windings of coils and armatures. It is estimated that a saving in weight of 50 per cent. is possible in armatures, with a corresponding reduction in mechanical stresses at high speeds. Such insulation would be unaffected by temperatures approaching the melting point of aluminium itself.

STRUCTURE AND TRANSPORT.

For general utilisation on a large scale anodised aluminium has two advantages—resistance to corrosion and decorative effect. It finds its oldest and widest application in aircraft, where the first of these is at a premium, and where the chromic acid process gives a very satisfactory strong grey finish. This usage has extended to shipbuilding; the battle-cruiser "Strasbourg" and the liners "Queen Mary," "Strathmore," and "Normandie" embody anodised aluminium (product of the sulphuric acid processes), much of which is very decorative. It has found its way to the interior fittings of many road and rail transport vehicles, and will probably be employed for their exterior bodywork also.

Architecturally, it has been employed extensively for window frames, shop fronts and fittings, and decoration. The shades of colour obtainable are delicate and consistent, but visible welds must be avoided, as these are accentuated by the anodising treatment. Possibly this difficulty will be overcome before long.

One more chapter is in process of being written in the fascinating history of aluminium. It is too early yet to see where it will lead us, but the possibilities are manifold.

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The Attack of Brass by Moist Ammonia.

IT was long ago established that in the season cracking of brass two factors were of importance: first, the internal stress existing in the material; and secondly, the presence of an active agent, usually ammonia or a volatile ammonium compound. Solutions of mercury salts have an intense surface effect on stressed brass leading to intercrystalline penetration and failure, but ammonia penetrates deeply into the interior of the material and destroys its structure.

This aspect of the action of ammonia is illustrated by some experiments of J. Czochralski and H. Schreiber, described in a paper on "The Corrosion of Brass in Moist Ammonia Atmospheres."*

They took tensile test pieces cut from brass sheet, 1·5 mm. thick, having the following composition and hardness, one series being cut parallel and one perpendicular to the direction of rolling:—

Composition, Cu : Zn	60 : 40	67 : 33	80 : 20	85 : 15
Vickers D.P. hardness (20 kg. load)...	154	149	67	74

The test pieces were hung on glass hooks in a large

* *Korrosion und Metallschutz*, June, 1937, 13, 181–183.

desiccator at the bottom of which stood a small dish of concentrated ammonia solution. To avoid fracture in the grips, the ends of the test pieces were covered with a thick layer of paraffin wax. Tensile tests were made after exposure to ammonia for 0, 2, 4, 8, 12, and 24 hours and for 2, 4, 7, and 15 days.

The results are presented in the form of curves from which the data given in Table I are extracted.

TABLE I.—*Effect of Exposure to Ammonia on the Tensile Properties of Cold-rolled Brass Strip.*

Copper per cent. and direction relative to direction of rolling.	Tensile strength, kilos. per sq. mm., after exposure for			Elongation, per cent., after exposure for		
	0	1 day	7 days	0	1 day	7 days
60 parallel annealed	48	45	44	30	27	25
67 perpr. annealed	47	44	40	18	12	9
60 parallel	50	41	25	18	4	nil
60 perpendicular ...	50	19	12	18	1	nil
67 parallel	47	30	20	11	1	nil
67 perpendicular ...	47	20	12	10	nil	nil
80 parallel	30	27	25	55	43	39
80 perpendicular ...	31	26	23	60	33	21
85 parallel	29	27	26	43	36	35
85 perpendicular ...	29	27	25	43	35	33

The tensile strength and elongation fell more quickly in the specimens cut perpendicular than in those cut parallel to the direction of rolling. They began to fall after about 3 or 4 hours in the 60 and 67 per cent. copper alloys and after about 6 or 8 hours in those containing 15 and 20 per cent. copper. In 4 days the elongation of the 60 : 40 and 67 : 33 alloys was reduced to nil and the tensile strength to one-quarter of the original value. The 80 : 20 and 85 : 15 alloys showed a smaller, but still considerable fall of tensile strength and elongation. The same 60 and 67 per cent. copper alloys annealed for 25 minutes at 325 deg. were only slightly affected by the ammonia.

Some important factors, as, for example, the degree of cold work, and the distribution of the internal stresses present, were not adequately taken into consideration in these experiments, which, however, clearly demonstrate the powerful action exerted by moist ammonia on the mechanical properties of brass which is in a condition of internal stress. More trustworthy quantitative information would have been obtained by subjecting the annealed brass to the action of ammonia under a definite imposed static load. The cause of the period of induction before rapid attack was not discussed. It is probably connected with the structure of the surface layer of amorphous material present on the sheet.

Books and Publications.

Metallic Corrosion, Passivity, and Protection. By U. R. EVANS. Med. 8vo, pp. xxiv+720. 1937. London: Edward Arnold and Co. 45s.

REMARKABLE advances in the knowledge of the causes of corrosion and of the factors controlling its development have been made during the past ten years. The subject has become so specialised that only those who have carefully followed the developments can appreciate the reasons for the numerous qualifications with which the corrosion expert is obliged to surround his prophecies. A comprehensive treatment of the subject by such a recognised authority as Dr. U. R. Evans is thus to be welcomed.

Corrosion is defined as destruction by chemical or electrochemical agencies. From a practical point of view, corrosion is chiefly connected with the wastage of metal exposed at ordinary temperatures to the atmosphere or immersed in liquids, but it may also be applied to destruction caused by exposure at high temperatures to air or to other gases.

The two main features of the modern viewpoint of corrosion are the presence of films on metals and the electrochemical nature of corrosion.

Oxide films formed at air temperature are of primary importance in determining the behaviour of certain metals (for example, chromium, stainless steels, and aluminium), and they may determine the initial distribution of corrosion on more corrodible metals; the manner of growth and the properties of oxide films also determine the resistance of metals to destruction at high temperatures. Approximately one-eighth part of Dr. Evans' book is devoted to the practical and scientific consideration of oxide films, including a section on the pickling of metals for removal of oxides.

Whilst the atmospheric corrosion of metals, especially of ferrous metals, is given adequate treatment, greater prominence is given to wet corrosion. In wet corrosion, the flow of electric currents at room temperatures is now established, and methods have been devised for measuring the "corrosion current" which has been stated to be capable, under certain conditions, of approximate correlation with the amount of metal destroyed. The metal is attacked at the anodic areas and is protected at the cathodic areas, where, in approximately neutral electrolytes, the liquid may be rendered sufficiently alkaline to inhibit attack. Complications arise, however, by the shift of the anodic and cathodic areas as corrosion proceeds and, although the total rate of corrosion may remain substantially unaltered, areas which were initially cathodic may later become extensively attacked. The incidence of corrosion and its progress with time are, in fact, determined by a large number of factors, some arising entirely from the external environment, others due to the composition, structure, and surface condition of the metal itself.

In view of the varied and complicated nature of wet corrosion processes, it is not surprising that disagreement has been registered between different workers. In his preface, however, Dr. Evans comments that "the idea that corrosion research is engulfed in controversy is to-day an exaggeration. . . . Taking the matter as a whole, it is not the disagreement, but the basic accord which appeals to the author as both surprising and comforting." One of the chief bones of contention is the differential aeration principle, which postulates that the depolarising influence of oxygen encourages the well-aerated areas to function as cathodes, corrosion being concentrated at the more poorly aerated regions which function as anodes. That this process can occur is beyond dispute, but there is no doubt that the application of the principle has been abused, particularly by those who, not appreciating the complexity of corrosion processes, have applied the principle indiscriminately. In this connection, a useful inclusion in the book is a condensed statement of their views specially contributed by Drs. Bengough and Wormwell, who have consistently challenged the importance of the differential aeration principle.

One of the most useful sections of the book to metallurgists and engineers deals at length with the influence of the major and minor constituents of the metal and with the influence of stress and strain;

these combined sections occupy nearly one-quarter of the total space.

The arrangement of metals in the order of their normal potentials provides a rough guide to their corrodibility, but many anomalies are encountered due to the controlling effect of factors such as oxide films (for example, aluminium and chromium), the solubility of hydroxides in the corroding liquid, and hydrogen over-voltage. The rate of corrosion of magnesium in sodium chloride solutions, for example, has been found to bear a close parallelism to the solubility of its hydroxide in the solution; and pure zinc is attacked less rapidly by pure acids than iron, owing to its higher hydrogen over-voltage. A somewhat closer correlation of corrodibility with the periodic table appears to be possible, although anomalies are again encountered, for example, in the abnormal behaviour of the transition elements (iron, cobalt, nickel, and the six platinum metals). This abnormal behaviour may be explained on the basis of the supposition that the lattice of these metals contains no ions, in contrast to other metals whose lattice structure is built up of ions with free electrons intervening.

Considerable interest is naturally attached to the relation between the structure and corrodibility of alloys. The development of improved corrosion resistance by the use of alloying elements is a problem which has been widely studied by manufacturers and there are probably potential improvements in protective coatings to be secured by the introduction of alloying elements. Many of the data available are, however, of an empirical nature and the subject does not admit of much generalisation in the present state of knowledge. Dr. Evans has, however, devoted a section to the theoretical consideration of the principles involved, which is of considerable value as a basis for further investigation. On the practical side the survey of materials for use in the chemical industries, building, water supply, food manufacture and cooking, oil industry, and for use at sea is an essential and important feature of the book.

The effect of minor constituents on corrodibility must be regarded, in the light of recent research, as at least of equal importance to that of major constituents, at any rate in the ferrous industry. Whilst the presence of small amounts of alloying elements or impurities frequently accelerates corrosion (for example, sulphur in steel exposed to acid attack), it sometimes retards corrosion (for example, arsenic in copper, copper in iron). Minor constituents may also have an important influence on intergranular corrosion (*e.g.*, titanium is beneficial in chromium-nickel steels, whilst copper is detrimental in aluminium alloys).

The influence of straining applied previous to corrosion varies according to conditions. It is customary to regard locally strained metal as specially susceptible to attack, but whilst this is usually true of corrosion in acid media, it is not generally applicable to corrosion which is controlled by rate of oxygen supply; also, if the corrosion is determined by the perfection of an oxide film, the detrimental effect of straining will depend upon its influence on the continuity of the film and upon the effect of subsequent exposure to air on the repair of the film. A large part of the chapter on stress and strain is devoted to the practical and theoretical consideration of corrosion fatigue.

Whilst engineers wisely endeavour to avoid contact of dissimilar metals on parts subject to corrosive attack, such contact is not always unduly detrimental and a careful examination of the principles involved is therefore of interest. Thus, for example, in a liquid of good conductivity in which the corrosion products are not formed in such close contact that they tend to localise attack, contact of a small area of a more noble metal of high hydrogen over-voltage will probably not accelerate corrosion to a marked degree, whereas if the area of the more noble metal is large, corrosion of the anodic metal will probably be markedly stimulated. Zinc "protectors" are used to concentrate corrosion on an easily renewed part, for example, in ships (to protect propellers, rudders, hulls, marine boilers), in fire engines, and in aircraft.

One chapter is devoted to protection by metallic coatings and the treatment of this subject is therefore highly condensed. A useful and up-to-date summary of information on hot dipping, electrodeposition, metal spraying, &c., is, however, provided.

The protective quality of paint coatings is a complicated subject, which is clearly and usefully expounded. On ferrous metals the inhibitive action of certain pigments such as litharge, red lead, zinc dust, zinc oxide, &c., indicates the advisability of their use in the priming coats, whilst water-tightness, flexibility, and adhesion are properties which are desirable in the finishing coats. From the practical point of view the condition of the metal at the time of painting is at least as important as the composition of the paint used. Moisture, salts, rust, and particles of scale or other non-metallic matter below the paint film may lead to unduly rapid failure of the paint coating for various reasons. Much practical information on the painting of structures and on marine painting is given.

The book concludes with an important chapter on methods of corrosion testing and on the testing of metallic and paint coatings and there is an appendix on the optical measurement of the thickness of oxide films on metals.

The novel arrangement of each chapter in three sections—scientific basis, practical problems and quantitative treatment—is commendable. A good case has been made for the use of statistical methods in corrosion research, for example, but this information, whilst of undoubted interest to research workers, will probably not appeal to readers interested only in results, and its segregation into the quantitative sections improves the readability of the book. Approximately one-sixth of the space is devoted to the quantitative treatments, the remainder being equally divided between the sections on "scientific basis" and on "practical problems." No space is wasted on expounding the elementary principles of metallurgy or electrochemistry, but a few long footnotes have been included to provide a reminder of modern views on subjects, such as the ionic dissociation of electrolytes and the structure of metals, with which the reader should be acquainted.

The book is not fully illustrated, and whilst the use of sketches makes written descriptions of the appearance of specimens much clearer, the omission of photographs of actual specimens, microstructures, and, in fact, of any half-tone illustrations, is regrettable. The author's facility for producing explanations which might be regarded as having inadequate foundation in experimental results may be a feature of the book which could be criticised, but care has been taken to qualify these explanations as tentative, and, if this is recognised, they will then be found to be valuable as a basis for further investigation or discussion. In a work of this size and scope many criticisms on points of detail could be made, but full

credit must be given to the author for producing a treatise of remarkable utility and abundantly provided with references.

Gases and Metals. By C. J. SMITHELLS. Demy 8vo. Pp. vii+218. 1937. London: Chapman and Hall, Ltd. 18s.

IN this book, which is described as "an introduction to the study of gas-metal equilibria," Dr. Smithells has assembled the available data on the physical relations between gases and metals covered by the headings adsorption, diffusion, and solution. This information has hitherto remained scattered over a wide field of scientific literature, and the book will therefore be of great value to the large number of metallurgists who are interested in the relations between gases and metals, and in particular to all investigators in the subject. Although it deals adequately with the underlying theory, it is clearly the work of one who is primarily interested in experiment, and contains detailed descriptions of practical methods of the study of gas-metal systems, with comments on precautions to be taken and sources of error which are to be guarded against. The book is not concerned with chemical reactions between gases and metals, and does not deal at any length with catalytic reactions at metal surfaces, but it contains much essential information about adsorption which chemical books dealing with metal catalysts frequently omit.

The restriction of the subject matter to gases and metals rather than gases and solids is entirely justified not only on the ground of the special interests of metallurgists, but by reason of the fundamental differences in the behaviour of metals and of other solids. This is clearly shown, for example, in connection with diffusion. Gases diffuse through metals in the atomic, and not the molecular state. Dissociation takes place when the gas molecule is adsorbed. Activated adsorption, in which the gas atoms are linked directly to the metal atoms of the surface, is a necessary preliminary to diffusion; and only those gases which undergo activated adsorption by a metal can diffuse through it. The rare gases (helium, argon, &c.) are not adsorbed in this way by any metal, and all attempts to measure their diffusion through various metals have given negative results. On the other hand, the diffusion of gases through glass and silica is of an entirely different character. The gas diffuses in the molecular state and the rare gases diffuse quite readily.

Dr. Smithells' own work on diffusion guarantees that this part of the subject receives excellent treatment, and a valuable feature of the book is the manner in which the intimate connection between adsorption, diffusion, and solution is revealed and emphasised. In direct effect on metallurgical properties solution is the most important of these three phenomena. But here it may be stated that practical applications, such as the production of sound ingots, are not within the scope of the book. Many such applications are, however, briefly mentioned. The embrittling effect of hydrogen in pickling is dealt with at some length, the alleged effect of hydrogen on the structure and properties of electro-deposits is also discussed, but the important influence on steel of the gases taken up during manufacture is hardly mentioned. Though the practical metallurgist would have welcomed a much fuller treatment of such aspects of the subject, he will find in Dr. Smithells' book a very full and authoritative account of the characteristics of the behaviour of gases and metals, and much that will help him, if not to solve all his problems, at least to correct his speculations.

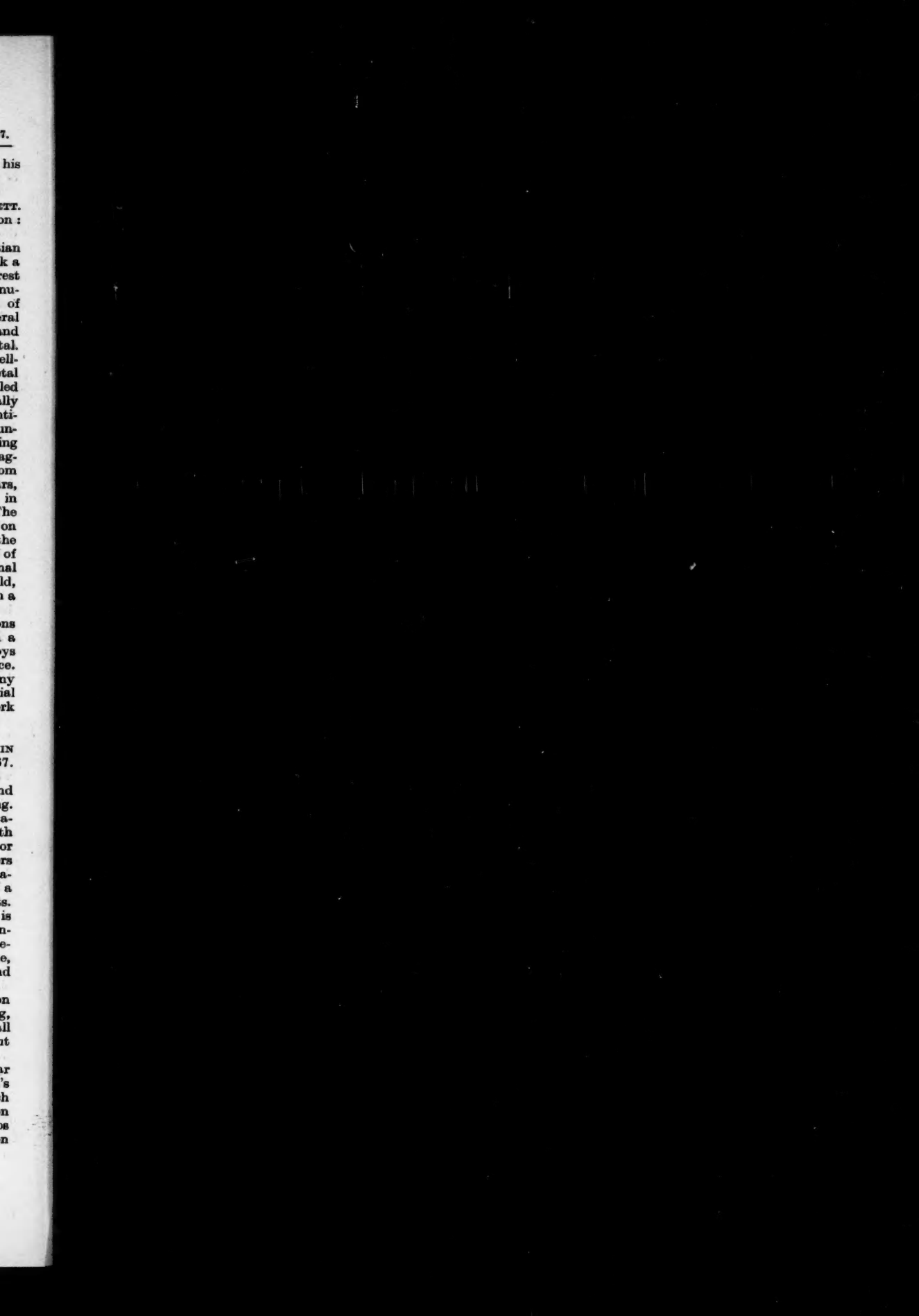
Bearing Metals and Alloys. By H. N. BASSETT. Demy 8vo, pp. xiv+428. 1937. London: Edward Arnold and Co. 25s.

THE author, who is Chief Chemist to the Egyptian State Railways, has collected together in this book a very large amount of information, chiefly of interest to the user, but of vital importance also to manufacturers of bearing metals and to investigators of their properties. The book deals with the general questions of lubrication, hot bearings, seizing, and structure in relation to suitability as a bearing metal. In this connection there are a number of well-reproduced illustrations of typical bearing metal structures. In the main it consists of a detailed account of the properties of a great variety of actually employed or possible bearing metals, *e.g.*, white anti-friction metals, copper alloys, zinc bronzes, gun-metals, lead bronzes, phosphor-bronzes, and bearing metals whose base is cadmium, aluminium, magnesium, or zinc. This information is reproduced from the author's card index kept over a number of years, and it displays its origin by a certain abruptness in the transition from one paragraph to the next. The book, therefore, though encyclopædic in its scope on matters relating to bearing metals, suffers by the absence of a considered judgment on the value of much of the information it contains. The personal experience on which to base such a judgment would, it must be admitted, be hard to come by over such a range as the book covers.

The "safe" materials, or well-tried modifications of standard alloys, are admirably summarised in a very useful table of compositions representing alloys which have been found to give satisfactory service. As for the rest, the reader is well served in any further inquiry he may wish to make about special alloys, by the full references to the original work which are given throughout the book.

Réactifs d'Attaque Métallographique. By A. PORTEVIN and P. BASTIEN. 13×21 cm., pp. xviii+267. 1937. Paris: Dunod. 87·25f.

THE list of reagents employed in the macro- and micro-examination of metals is constantly increasing. Information about them is spread over many publications in different languages. Books dealing with metallography usually mention only selected or recommended reagents. Investigators and others dealing with specialised problems want wider information as a basis for making their final selection of a method of etching suitable for their requirements. Such information this book will provide, and it is rendered easily accessible by a detailed table of contents followed at the end of the book by a three-fold index classified under (1) the author's name, (2) the metal, alloy or constituent examined, and (3) the principal compound present in the reagent.

Although the authors have written a special section on the general principles of metallographic etching, they have naturally not examined the behaviour of all the reagents mentioned, and the information about them is recorded as published.

There exist in English books which cover similar ground, notably Dearden's translation of Berglund's "Metallographers' Handbook of Etching," to which the authors pay a tribute, but the present publication carries the subject a little further and is perhaps rather more exhaustive and complete, especially on the non-ferrous side.